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FURTHER FLOTATION BENEFICIATION STUDIES ON A SAMPLE OF KAOLIN FROM BLACK ISLAND, MANITOBA

P.R.A. Andrews and L. Morin
Mineral Processing Laboratory

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FURTHER FLOTATION BENEFICIATION STUDIES ON A SAMPLE OF KAOLIN FROM BLACK ISLAND, MANITOBA

by

P.R.A. Andrews* and L. Morin**

ABSTRACT

Approximately 160 kg of a sample of kaolin-silica sand was scrubbed and sized. The -44 µm fraction, which contained most of the kaolin, was further classified at 3 µm using a laboratory hydrocyclone. The -3 µm fraction analysed ≈34% Al_2O_3 and did not require further beneficiation. The intermediate -44 +3 µm fraction analysing ≈21% Al_2O_3 was beneficiated by flotation.

A variety of collectors at several pH values using sodium silicate as a quartz depressant were evaluated. A grade of 34.8% Al_2O_3 was achieved but only at a low recovery of 34.8%. The reasons for the low recoveries are due mainly to the problems encountered with fine particle flotation. Recovery can be improved but precise control of flotation parameters would be required.

Brightness values of only 67.3 were obtained on iron-reduced kaolin concentrates. It is considered that a possible reason for this low brightness value is that the sample, received in a wet state, was contaminated by corrosive attack of the metal containers.

Keywords: kaolin, flotation, Black Island, iron oxide, fine-particle beneficiation.

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* Minerals Engineer and **Technician, Non-Metallic Mineral Section, Mineral Processing Laboratory, Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada, Ottawa.

ÉTUDES SUPPLÉMENTAIRES SUR L'ENRICHISSEMENT PAR FLOTTATION D'UN ÉCHANTILLON DE KAOLIN PROVENANT DE BLACK ISLAND (MANITOBA)

par

P.R.A. Andrews* et L. Morin**

RÉSUMÉ

On a lessivé et calibré un échantillon de sable de kaolin et de silice d'environ 160 kg. La fraction de -44 µm, qui contenait la majeure partie du kaolin, a été classifiée à 3 µm une autre fois à l'aide d'un hydrocyclone de laboratoire. La fraction de -3 µm analysée était presque égale à 34 % d'Al_2O_3 et ne nécessitait aucun enrichissement supplémentaire. La fraction intermédiaire de -44 +3 µm dont l'analyse donnait presque 21 % d'Al_2O_3 a été enrichie par flottation.

On a évalué divers collecteurs à plusieurs niveaux de pH au moyen de silicate de sodium en tant que déprimant du quartz. Des teneurs de 36 % d'Al_2O_3 ont été atteintes mais seulement à des taux de récupération de 30 à 35 %. Ces faibles taux sont surtout attribuables aux problèmes survenus lors de la flottation des particules fines. Le taux de récupération peut être augmenté, mais un contrôle précis des paramètres de flottation serait nécessaire.

Des valeurs de brillance de seulement 67,3 ont été obtenues sur les concentrés de kaolin réduits de fer. On croit que la faible valeur de brillance peut être due au fait que l'échantillon, reçu à l'état mouillé, ait été contaminé par une attaque corrosive des contenants métalliques.

MOTS-CLÉS : kaolin, flottation, Black Island, oxyde de fer, enrichissement des particules fines.

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* Ingénieur en minéralogie et ** Technicien, Section des minéraux non métalliques, Laboratoire de traitement des minéraux, Centre canadien de la technologie des minéraux et de l'énergie, Énergie, Mines et Ressources Canada, Ottawa.

INTRODUCTION

During the early part of 1986 a preliminary beneficiation study was conducted on a sample of kaolin from Black Island. This study[1] indicated that silica concentrated predominantly in the +44 µm size range and kaolin in the -44 µm size range. The greatest concentration of kaolin, estimated to be ≈85% kaolin occurred in the -4 µm size fraction. The intermediate -44 +4 µm size fraction, being lower grade, was concentrated by flotation. Initial results indicated that ≈80% kaolin could be obtained but that further testwork was required to improve the recovery.

PROCESSING

HEAD SAMPLE

The remaining 157 kg of head material was dried at 30°C. The dried material was riffled into 10 kg portions, and each 10 kg was wet-scrubbed in the laboratory Wemco scrubber at 85% solids for 60 min. to allow the kaolin to be separated from the silica grit. Following scrubbing, the scrubbed products were washed to remove silica grit. This stage was accomplished by wet screening on 420 µm, 100 µm and 44 µm sieves. After settling of the -44µm portion, the clear water was decanted and the volume of wet slurry estimated. The slurry was divided into 3 L portions, each portion being further diluted to 10% solids and classified in a laboratory Mozley hydrocyclone, using maximum vortex (cyclone overflow) and spigot (cyclone underflow) diameters[2]. By employing these parametes a cyclone overflow with a cut point of 2.8µm was produced.

The resulting -44 +28 µm size fraction was decanted and kept in a wet state for flotation evaluation. All other products, with the exception of the -2.8 µm fraction were dried and weighed; results are reported in Table 1. The -2.8 µm fraction previously determined as being high grade was sampled only; a product balance for the -44 +2.8 µm and -2.8 µm fractions is reported in Table 2.

Flotation

In the previous study[1], the system Armac T-Na_2SiO_3 at pH 2 produced

a kaolin concentrate analysing =80% kaolin at 48.6% recovery. This preliminary evaluation was extended to include the optimization of this system by varying the pH, and concentration of Na_2SiO_3. In addition, other primary and secondary cationic collectors were evaluated to establish the optimum grade and recovery.

In the initial tests only stage addition collector rougher floats were conducted on 1 kg flotation feed samples. After establishing optimum conditions, rougher-cleaner tests were conducted on 2 kg flotation feed samples.

The product balances of all tests are reported in Table 3 and the reagent concentration values in Table 4.

RESULTS

Four collectors were evaluated which are described as follows:

MG 98 A3	Primary ether amine acetate
Armac T	Tallow amine acetate
Armac C	Coco amine acetate
Duomeen TDO	Tallow diamino - propane dioleate

Evaluation of MG 98 A3

At pH 6.5 MG 98 A3 was unselective in floating kaolin. By decreasing the collector concentration from 168 g/t in Test 1 to 89 g/t in Test 2, less weight of concentrate was floated but recovery of kaolin decreased. When the pH was decreased to 2.0 in Test 14 and Na_2SiO_3, a slime dispersant and quartz depressant was added, a combined rougher concentrate analysing 24.6% Al_2O_3 at 82.8% recovery was obtained; however, 67.1% of the quartz floated. In Test 15 the pH was increased to 3.0 but there was very little difference in flotation performance. In both these tests there was a slight increase in grade with increasing number of rougher floats, indicating that this collector was slow to respond to kaolin flotation. Subsequent, further testwork was conducted in this pH range (2.0 to 3.0), and up to 5.0 to ascertain whether a similar increase in grade occurred at higher pH values. In addition, rougher flotation was extended to include two stages of

cleaning; sodium silicate being added in both the rougher and cleaner stages. The best performance was achieved at pH 2.0 in Test 24. A cleaner concentrate was obtained after three stages of cleaning, which analysed 35.6% Al_2O_3 for a recovery of 21.3%. After two stages of cleaning a cleaner concentrate analysed 33.1% for a recovery of 37.2%. Increasing the pH to 3.0 in Test 25 reduced both grade and recovery, since a cleaner concentrate after two stages of cleaning analysed only 30.1% Al_2O_3 with a recovery of 32.9%. Further increase of pH to 4.0 significantly reduced selectivity and the quartz was not effectively depressed; a cleaner concentrate after two stages of cleaning analysed only 25.3% Al_2O_3.

Evaluation of Armac T

In Tests 4, 5 and 6 the influence of increasing the concentration of sodium silicate was investigated at pH 2.0. When using 1390 g/t Na_2SiO_3 in Test 4, a combined rougher concentrate after three floats was obtained analysing 26.2% Al_2O_3 at a recovery of 69.9%. Increasing the concentration to 9,940 g/t Na_2SiO_3 did not significantly improve either grade or recovery, and the amount of quartz depression was not increased. In Test 4, 68.6% of the quartz was depressed and in Test 6 only 44.6% was depressed, based on combined three-float rougher concentrates.

The influence of pH was investigated in Tests 10 to 13 while maintaining constant collector and sodium silicate concentration; the average collector concentration was 437 g/t and the average sodium silicate concentration 1750 g/t. By increasing the pH from 3.0 to 5.0 the grade and recovery of a combined three-float rougher concentrate increased slightly; 23.2% Al_2O_3 at 76.0% recovery for Test 10; 23.5% Al_2O_3 at 79.6% recovery for Test 11 and 24.7% Al_2O_3 at 83.3% recovery for Test 12. In Test 13, at pH 6.0 the weight % of a three-float rougher concentrate was considerably reduced to 50.5%; a grade of 25.1% Al_2O_3 at a recovery of 60.4% indicated unselective flotation conditions.

The relative success achieved at pH 5.0 in Test 12, was extended to include a cleaning stage in Test 16. Although sodium silicate was used in the rougher float, the absence of both collector and depressant in the cleaner stage resulted in an unselective float. In Test 18, collector was introduced into the cleaner stage and a concentrate after three stages of

cleaning was obtained analysing 29.7% Al_2O_3 at 16.1% recovery, clearly an unselective float. In Test 23 the pH was reduced to 3.0 and sodium silicate added in the cleaning stage; collector was added in both the rougher and the cleaner stages. A cleaner concentrate after two stages of cleaning was obtained analysing 34.4% Al_2O_3 at only 13.9% recovery.

Evaluation of Armac C

In Tests 7, 8 and 9 the effect of increasing the concentration of sodium silicate was investigated at pH 2.0. When using 1,030 g/t Na_2SiO_3, the lowest concentration, a combined three-float rougher concentrate was obtained analysing 23.5% Al_2O_3 at 97.5% recovery. Increasing the concentration of sodium silicate to 2,030 g/t in Test 8, and to 3,010 g/t in Test 9 did not significantly alter either grade or recovery. In each test ≈85% of the weight floated in a three-float combined rougher concentrate, with very little evidence of quartz depression.

The effect of pH variation was investigated in Tests 20, 21 and 22. In Test 20, at pH 5.0 no selectivity was achieved even after three stages of cleaning. At pH 3.0, Test 21 produced a more selective float, where after two stages of cleaning a concentrate was obtained analysing 29.0% Al_2O_3; recovery was low at 42.6%. In Test 22, performed at pH 2.0, collector concentration was increased in the cleaners in order to improve both grade and recovery. After two stages of cleaning a concentrate analysing 32.2% Al_2O_3 at 34.6% recovery was obtained.

Evaluation of Duomeen TDO

Two tests only were conducted with this collector at pH 2.0. Test 27, a four-stage rougher float indicated that Duomeen TDO was slow to respond, since the grade increased from 24.0% Al_2O_3 for rougher float 1 to 30.4% Al_2O_3 for rougher float 4. In Test 28 a concentrate analysing 34.8% Al_2O_3 at a recovery of 34.3% was obtained after only one stage of cleaning.

Influence of pH

When using Duomeen TDO and Armac C, selective flotation conditions were obtained only at pH 2.0. Despite an encouraging result with Armac T for the combined rougher float, success was not repeated when a cleaner stage was

introduced. In fact, even at pH 3.0, results were not as good as those results obtained at pH 2.0 in the previous investigation[1]. The best results when using MG 98 A3 were likewise obtained at pH 2.0.

Influence of sodium silicate

When using either Armac T or Armac C, a concentration of 1,000 to 1,400 g/t Na_2SiO_3 was found to be sufficient for pulp dispersion and aiding grade and recovery of kaolin concentrates. Increasing the concentration of sodium silicate did not improve either grade or recovery of kaolin, and the ability of sodium silicate to depress quartz could not be effectively determined.

DISCUSSION AND RESULTS

When conducting fine particle flotation, reagent consumptions increase and selectivity generally decreases unless precise control is exercised on flotation parameters. Such control is exacting and beyond the facilities of this laboratory. Consequently, while kaolin was concentrated to high levels of Al_2O_3, recoveries were poor. A summary of the best results is presented as follows:

Test No.	Grade			Recovery
	$\%Al_2O_3$	$\%Fe_2O_3$	$\%TiO_2$	$\%Al_2O_3$
24	35.6 (33.1)	0.88 (0.87)	0.35 (0.46)	21.3 (37.2)
23	36.1 (34.4)	1.12 (1.06)	0.23 (0.32)	10.5 (13.9)
28	36.4 (34.8)	1.23 (1.09)	0.19 (0.35)	16.4 (34.3)

The figures in parentheses refer to the penultimate cleaning stage for that particular test. The best performance was Test 28 which not only produced the highest grade, but required only two cleaning stages to produce a grade of 36.4% Al_2O_3. Tests 23 and 24 required three cleaning stages to produce comparable grades. Whilst the recoveries in these tests were

unacceptably low, careful control of flotation variables should increase recovery.

Iron oxide tends to concentrate with the kaolin; the analysis of Test 28 final concentrate was 1.23% Fe_2O_3. This high concentration of Fe_2O_3 resulted in a low brightness value of 57.4. An acid leach with 50% hydrochloric acid removed free iron oxide (equivalent to high intensity magnetic separation), and increased the brightness to 67.3. Titanium dioxide does not follow the same trend as iron oxide, rather concentration decreases with increasing concentration of kaolin.

The weight recovery of 34.0% Al_2O_3 grade kaolin is 10.6% for the -44 +3 μm fraction and 46.5% for the -3 μm fraction.

CONCLUSIONS

The intermediate size product -44 +3 μm kaolin fraction can be upgraded on a laboratory scale to 36% Al_2O_3, but recoveries are low. The collector which produced the best results was Duomeen TDO at pH 2.0 using sodium silicate as a quartz depressant.

The highest brightness value obtained was 67.3 which would suggest low-grade filler quality. A possible explanation for this low value was that the original sample was contaminated. The sample was shipped in a wet state in metal drums and the inside surfaces of some of the drums exhibited considerable corrosion attack. This could explain why there was a slight yellow tinge to the kaolin.

RECOMMENDATIONS

It is recommended that Test 28 conditions for the intermediate product size -44 +3 μm be repeated on more representative material from different parts of the deposit. If further laboratory studies were successful, then pilot-plant evaluation would be warranted. Transport of the samples in a dry state in plastic bags would reduce the probability of contamination.

REFERENCES

1. Andrews, P.R.A., "Evaluation of a sample of kaolin from Black Island, Manitoba as source material for the paper industry"; Division Report MSL 86-79 (IR); CANMET, Energy, Mines and Resources Canada; June 1986.

Table 1. Size analysis of head material

Product	Weight kg	Weight %
+420 µm	34.4	23.4
-420 +100 µm	25.9	17.7
-100 + 44 µm	9.1	6.2
- 44 + 3 µm	31.0	21.1
- 3 µm	46.5	31.6
Total	146.9	100.0

Table 2. Product balance for the -44 µm size fraction

Product	Weight %
-44 +3 µm	40.0
-3 µm	60.0
Total	100.0

Table 3. Product balance

Test No	Products	Wt %	Analysis %			Distribution %		
			Al_2O_3	Fe_2O_3	SiO_2	Al_2O_3	Fe_2O_3	SiO_2
1	1st rgh. conc.	75.1	21.7	0.66	66.9	77.8	78.1	74.1
	Rgh. tails	24.9	18.7	0.56	70.7	22.2	21.9	25.9
	Calculated head	100.0	21.0	0.63	67.8	100.0	100.0	100.0
2	1st rgh. float	25.7	23.2	0.79	64.0	28.6	32.2	24.3
	2nd rgh. float	12.4	22.7	0.71	65.5	13.5	13.9	12.0
	3rd rgh. float	16.9	22.5	0.63	65.7	18.2	16.8	16.4
	Rgh. tails	45.0	18.4	0.52	71.2	39.7	37.1	47.3
	Head (calculated)	100.0	20.9	0.63	67.7	100.0	100.0	100.0
3	1st rgh. float	9.0	24.5	0.87	61.3	10.5	12.5	8.0
	2nd rgh. float	24.5	24.1	0.75	63.1	28.2	29.5	22.5
	3rd rgh. float	17.8	21.9	0.66	66.4	18.6	18.9	18.6
	Rgh. tails	48.7	18.4	0.50	72.0	42.7	39.1	50.9
	Head (calculated)	100.0	21.0	0.62	68.9	100.0	100.0	100.0
4	1st rgh. float	15.4	26.1	0.81	61.3	18.7	19.9	13.5
	2nd rgh. float	24.3	26.5	0.78	60.2	30.0	30.0	20.9
	3rd rgh. float	17.2	25.9	0.73	61.3	20.8	20.0	15.0
	4th rgh. float	14.9	24.6	0.68	63.4	19.7	18.7	15.6
	5th rgh. float	7.3	21.3	0.59	66.8	7.3	6.8	6.9
	Rgh. tails	20.9	3.5	0.14	94.4	3.5	4.6	28.1
	Head (calculated)	100.0	21.4	0.63	70.1	100.0	100.0	100.0
5	1st rgh. float	32.5	25.3	0.77	63.0	39.2	40.6	29.8
	2nd rgh. float	17.5	26.7	0.76	60.3	22.2	21.6	15.3
	3rd rgh. float	18.6	25.8	0.72	61.5	22.8	21.8	16.6
	4th rgh. float	8.9	23.5	0.64	64.1	10.0	9.2	8.3
	5th rgh. float	4.7	14.8	0.45	78.2	3.3	3.4	5.3
	Rgh. tails	17.8	2.9	0.12	95.0	2.5	3.4	24.7
	Head (calculated)	100.0	21.0	0.62	68.8	100.0	100.0	100.0
6	1st rgh. float	23.3	25.1	0.78	63.7	28.2	29.3	21.6
	2nd rgh. float	18.8	25.6	0.77	60.4	23.2	23.3	16.5
	3rd rgh. float	19.2	25.7	0.75	62.0	23.8	23.2	17.3
	4th rgh. float	8.4	23.9	0.67	63.4	9.7	9.0	7.8
	5th rgh. conc.	5.4	23.6	0.65	63.1	6.1	5.6	4.9
	Rgh. tails	24.9	7.5	0.24	88.2	9.0	9.6	31.9
	Head (calculated)	100.0	20.7	0.62	68.8	100.0	100.0	100.0

Table 3. Product balance (cont'd)

Test No	Products	Wt %	Analysis %			Distribution %		
			Al_2O_3	Fe_2O_3	SiO_2	Al_2O_3	Fe_2O_3	SiO_2
7	1st rgh. float	59.7	23.7	0.68	65.1	66.9	66.2	56.9
	2nd rgh. float	21.7	24.1	0.67	62.7	24.7	23.6	19.9
	3rd rgh. float	6.3	19.9	0.59	68.2	5.9	6.0	6.3
	4th rgh. float	2.6	9.9	0.37	84.6	1.2	1.6	3.3
	Rgh. tails	9.7	2.8	0.16	96.0	1.3	2.6	13.6
	Head (calculated)	100.0	21.2	0.61	68.3	100.0	100.0	100.0
8	1st rgh. float	55.7	23.6	0.67	64.1	62.2	61.4	52.6
	2nd rgh. float	20.3	24.9	0.68	62.4	23.9	22.8	18.7
	3rd rgh. float	8.9	21.7	0.63	66.1	9.1	9.2	8.7
	4th rgh. float	3.6	16.3	0.51	75.6	2.8	3.0	4.0
	Rgh. tails	11.5	3.6	0.19	94.4	2.0	3.6	16.0
	Head (calculated)	100.0	21.1	0.61	67.8	100.0	100.0	100.0
9	1st rgh. float	61.9	23.4	0.68	63.9	69.0	68.3	59.0
	2nd rgh. float	19.3	24.0	0.67	62.9	22.1	20.9	18.1
	3rd rgh. float	6.9	19.3	0.59	69.0	6.3	6.7	6.5
	4th rgh. float	2.6	11.2	0.39	84.0	1.4	1.6	3.2
	Rgh. tails	9.3	2.7	0.16	95.0	1.2	2.5	13.2
	Head (calculated)	100.0	21.0	0.62	67.1	100.0	100.0	100.0
10	1st rgh. float	38.7	23.2	0.68	65.5	42.6	42.9	37.3
	2nd rgh. float	15.2	23.4	0.68	65.1	16.9	16.8	14.6
	3rd rgh. float	15.0	23.1	0.67	63.8	16.5	16.5	14.1
	4th rgh. float	13.6	23.7	0.68	64.1	15.3	15.0	12.8
	Rgh. tails	17.5	10.5	0.31	82.5	8.7	8.8	21.2
	Head (calculated)	100.0	21.1	0.61	68.0	100.0	100.0	100.0
11	1st rgh. float	29.9	23.0	0.69	65.8	32.7	33.6	29.0
	2nd rgh. float	24.5	24.2	0.73	62.6	28.2	29.2	22.6
	3rd rgh. float	16.8	23.4	0.66	64.8	18.7	18.0	16.0
	4th rgh. float	15.6	19.5	0.52	69.8	14.5	13.2	16.1
	Rgh. tails	13.2	9.4	0.28	84.0	5.9	6.0	16.3
	Head (calculated)	100.0	21.0	0.61	67.9	100.0	100.0	100.0
12	1st rgh. float	32.3	24.1	0.74	64.2	37.1	39.1	30.3
	2nd rgh. float	20.8	26.9	0.78	60.8	26.6	26.5	18.5
	3rd rgh. float	17.8	23.1	0.62	64.8	19.6	18.0	16.9
	4th rgh. float	19.6	14.0	0.38	78.2	13.0	12.1	22.4
	Rgh. tails	9.5	8.1	0.27	85.9	3.7	4.3	11.9
	Head (calculated)	100.0	21.0	0.61	68.4	100.0	100.0	100.0

Table 3. Product balance (cont'd)

Test No	Products	Wt %	Analysis %			Distribution %		
			Al_2O_3	Fe_2O_3	SiO_2	Al_2O_3	Fe_2O_3	SiO_2
13	1st rgh. float	10.0	24.8	0.77	63.6	11.8	12.7	9.3
	2nd rgh. float	22.0	24.8	0.74	63.4	26.0	26.8	20.3
	3rd rgh. float	18.5	25.6	0.74	61.5	22.6	22.6	16.6
	4th rgh. float	17.5	23.5	0.64	65.2	19.6	18.5	16.6
	Rgh. tails	32.0	13.1	0.37	79.8	20.0	19.4	37.2
	Head (calculated)	100.0	21.0	0.61	68.6	100.0	100.0	100.0
14	1st rgh. float	34.8	23.6	0.67	65.0	38.5	40.1	33.1
	2nd rgh. float	17.0	25.1	0.68	63.8	20.0	20.0	15.4
	3rd rgh. float	13.2	25.7	0.65	63.3	15.9	14.8	12.3
	4th rgh. float	6.9	26.0	0.66	62.5	8.4	7.7	6.3
	Rgh. tails	28.1	13.0	0.36	80.0	17.2	17.4	32.9
	Head (calculated)	100.0	21.3	0.58	68.3	100.0	100.0	100.0
15	1st rgh. float	30.7	22.9	0.66	66.7	33.0	33.7	29.6
	2nd rgh. float	20.1	24.2	0.68	65.1	22.8	22.9	19.0
	3rd rgh. float	13.2	25.7	0.70	62.8	15.9	15.3	12.0
	4th rgh. float	8.6	26.1	0.67	62.6	10.9	9.7	7.8
	Rgh. tails	27.4	13.6	0.40	79.5	17.4	18.4	31.6
	Head (calculated)	100.0	21.2	0.60	69.0	100.0	100.0	100.0
16	final conc.	55.3	18.6	0.55	74.3	47.9	49.8	58.4
	2nd cleaner tails	15.1	29.8	0.77	58.1	21.0	19.0	12.4
	1st cleaner tails	20.0	29.9	0.82	58.3	27.9	26.8	16.6
	(1st cleaner conc)	70.0	21.0	0.60	70.8	68.9	68.8	70.8
	Rougher tails	9.6	7.1	0.28	92.1	3.2	4.4	12.6
	(Rougher conc.)	90.4	23.0	0.65	68.1	96.8	95.6	87.4
	Head (calculated)	100.0	21.5	0.61	70.4	100.0	100.0	100.0
17	final conc.	28.5	19.5	0.58	72.7	26.0	27.3	30.0
	2nd cleaner tails	4.6	21.0	0.52	70.7	4.5	4.0	4.8
	1st cleaner tails	62.2	22.7	0.61	66.9	66.0	62.7	60.3
	(1st cleaner conc)	33.1	19.7	0.57	72.4	30.5	31.3	34.8
	Rougher tails	4.7	15.9	0.77	72.5	3.5	6.0	4.9
	(Rougher conc.)	95.3	21.7	0.60	68.8	96.5	94.0	95.1
	Head (calculated)	100.0	21.4	0.60	69.0	100.0	100.0	100.0
18	final conc.	11.1	29.7	0.77	58.1	16.1	14.6	9.3
	3rd cleaner tails	7.1	26.7	0.77	61.7	9.2	9.4	6.3
	2nd cleaner tails	10.8	22.9	0.68	66.0	12.1	12.5	10.3
	(2nd cleaner conc)	18.2	28.5	0.77	94.9	25.3	24.0	15.6
	1st cleaner tails	34.6	23.1	0.67	64.6	39.0	39.8	32.3
	(1st cleaner conc)	29.0	26.4	0.73	84.2	37.4	36.5	25.9
	Rougher tails	36.4	13.3	0.38	79.5	23.6	23.7	41.8
	(Rougher conc.)	63.6	24.6	0.70	73.5	76.4	76.3	58.2
	Head (calculated)	100.0	20.5	0.58	69.3	100.0	100.0	100.0

Table 3. Product balance (cont'd)

Test No	Products	Wt %	Analysis %			Distribution %		
			Al_2O_3	Fe_2O_3	SiO_2	Al_2O_3	Fe_2O_3	SiO_2
20	Final conc.	18.6	20.7	0.60	72.5	17.7	18.0	19.5
	3rd cleaner tails	7.8	25.6	0.74	63.7	9.2	9.3	7.2
	2nd cleaner tails	15.3	25.1	0.71	63.9	17.7	17.5	14.1
	(2nd cleaner conc.)	26.4	22.1	0.64	69.9	26.9	27.3	26.7
	1st cleaner tails	45.8	21.8	0.60	68.9	46.0	44.1	45.6
	(1st cleaner conc.)	41.7	23.2	0.67	67.7	44.6	44.8	40.6
	Rgh. tails	12.5	16.4	0.55	75.2	9.4	11.1	13.6
	(Rgh. conc.)	87.5	22.5	0.63	68.3	90.6	88.9	86.4
	Head (calculated)	100.0	21.7	0.62	69.2	100.0	100.0	100.0
21	Final conc.	13.7	31.6	0.85	55.6	22.5	21.0	10.6
	3rd cleaner tails	14.6	26.5	0.73	61.1	20.1	19.2	12.4
	2nd cleaner tails	19.0	18.8	0.53	73.2	18.6	18.3	19.3
	(2nd cleaner conc.)	28.3	29.0	0.78	58.4	42.6	40.2	23.0
	1st cleaner tails	38.6	11.5	0.39	81.8	23.1	27.4	43.7
	(1st cleaner conc.)	47.3	24.9	0.68	64.4	61.2	58.5	42.3
	Rgh. tails	14.1	21.4	0.55	72.0	15.7	14.1	14.0
	(Rgh. conc.)	85.9	18.9	0.55	72.2	84.3	85.9	86.0
	Head (calculated)	100.0	19.2	0.55	72.2	100.0	100.0	100.0
22	Final conc.	10.2	35.0	0.85	49.9	17.3	14.8	7.2
	3rd cleaner tails	12.0	29.8	0.81	56.6	17.3	16.6	9.7
	(2nd cleaner conc.)	22.2	32.2	0.83	53.5	34.6	31.4	16.9
	2nd cleaner tails	20.4	22.9	0.65	64.7	22.6	22.8	18.8
	(1st cleaner conc.)	42.6	27.7	0.74	58.9	57.2	54.2	35.7
	1st cleaner tails	40.0	17.3	0.51	76.6	33.6	34.9	43.6
	(Rgh. conc.)	82.6	22.7	0.63	67.5	90.8	89.1	79.3
	Rgh. tails	17.4	10.9	0.37	83.6	9.2	10.9	20.7
	Head (calculated)	100.0	20.6	0.58	70.3	100.0	100.0	100.0
23	Final conc.	6.1	36.1	1.12	48.3	10.5	11.5	4.3
	3rd cleaner tails	2.4	30.0	0.92	52.0	3.4	3.8	1.8
	(2nd cleaner conc.)	8.5	34.4	1.06	49.3	13.9	15.3	6.1
	2nd cleaner tails	7.5	27.6	0.83	60.1	9.9	10.5	6.5
	(1st cleaner conc.)	16.0	31.2	0.95	54.4	23.8	25.8	12.6
	1st cleaner tails	34.3	23.8	0.68	65.7	38.8	39.6	32.8
	(Rgh. conc.)	50.3	26.1	0.77	62.1	62.6	65.4	45.4
	Rgh. tails	49.7	15.8	0.41	75.7	37.4	34.6	54.6
	Head (calculated)	100.0	21.0	0.59	68.9	100.0	100.0	100.0

Table 3. Product balance (cont'd)

Test No	Products	Wt %	Analysis %			Distribution %		
			Al_2O_3	Fe_2O_3	SiO_2	Al_2O_3	Fe_2O_3	SiO_2
24	Final conc.	12.4	35.6	0.88	50.4	21.3	18.0	8.9
	3rd cleaner tails	10.9	30.3	0.85	56.8	15.9	15.3	8.8
	(2nd cleaner conc.)	23.3	33.1	0.87	53.4	37.2	33.3	17.7
	2nd cleaner tails	18.5	22.2	0.68	68.4	19.8	20.8	18.1
	(1st cleaner conc.)	41.8	28.3	0.78	60.3	57.0	54.1	35.8
	1st cleaner tails	37.2	19.1	0.57	73.0	34.3	34.9	38.7
	(Rgh. conc.)	79.0	24.0	0.68	66.1	91.3	89.0	74.5
	Rgh. tails	21.0	8.6	0.32	85.1	8.7	11.0	25.5
	Head (calculated)	100.0	20.7	0.61	70.1	100.0	100.0	100.0
25	Final conc.	11.1	32.3	0.74	54.9	17.2	14.2	8.2
	3rd cleaner tails	11.4	28.8	0.81	59.0	15.7	15.9	9.6
	(2nd cleaner conc.)	22.5	30.5	0.77	57.0	32.9	30.1	18.3
	2nd cleaner tails	20.9	24.1	0.63	65.4	24.1	22.9	19.5
	(1st cleaner conc.)	43.4	27.4	0.71	61.0	57.0	53.0	37.8
	1st cleaner tails	35.5	19.9	0.56	71.4	33.8	34.5	36.2
	(Rgh. conc.)	78.9	24.0	0.64	65.7	90.8	87.5	74.0
	Rgh. tails	21.1	9.1	0.34	86.2	9.2	12.5	26.0
	Head (calculated)	100.0	20.9	0.58	70.0	100.0	100.0	100.0
26	Final conc.	23.4	25.4	0.66	64.0	28.1	25.4	21.5
	3rd cleaner tails	15.5	25.2	0.71	63.9	18.5	18.2	14.2
	(2nd cleaner conc.)	38.9	25.3	0.68	64.0	46.6	43.6	35.7
	2nd cleaner tails	19.9	21.5	0.62	69.0	20.3	20.3	19.7
	(1st cleaner conc.)	58.8	24.2	0.66	65.7	66.9	63.9	55.4
	1st cleaner tails	31.3	18.3	0.54	75.5	27.1	27.8	33.1
	(Rgh. conc.)	90.1	22.0	0.62	68.4	94.0	91.7	88.5
	Rgh. tails	9.9	12.8	0.50	80.8	6.0	8.3	11.5
	Head (calculated)	100.0	21.1	0.61	69.6	100.0	100.0	100.0
27	1st rgh. float	23.3	24.0	0.78	65.6	26.2	30.5	22.0
	2nd rgh. float	12.3	26.2	0.79	63.2	15.1	16.3	11.2
	3rd rgh. float	8.6	29.2	0.76	58.6	11.7	10.9	7.3
	4th rgh. float	13.9	30.4	0.79	57.2	19.8	18.5	11.5
	Rgh. tails	41.9	13.9	0.34	79.6	27.2	23.8	48.0
	Head (calculated)	100.0	21.4	0.60	69.4	100.0	100.0	100.0
28	Final conc.	9.2	36.4	1.23	48.0	16.4	19.3	6.3
	2nd cleaner tails	10.9	33.5	0.97	51.4	17.9	18.2	8.0
	(1st cleaner conc.)	20.1	34.8	1.09	49.8	34.3	37.5	14.3
	1st cleaner tails	30.1	23.2	0.65	67.3	34.2	33.6	28.8
	(Rgh. conc.)	50.2	27.9	0.83	60.3	68.5	71.1	43.1
	Rgh. tails	49.8	12.9	0.34	80.3	31.5	28.9	56.9
	Head (calculated)	100.0	20.4	0.58	70.3	100.0	100.0	100.0

Table 4. Flotation parameter and reagent concentration data

Test No.	Flotation stage	No. of stage	Cond. time min.	Float time min.	pH	Pulp density % S	Impeller speed r.p.m.	Collectors			Na_2SiO_3 kg/t	D250 g/t	H_2SO_4 kg/t
								MG 98 A3 g/t	Armac T g/t	Armac C g/t			
1	Rougher	1	3	5.5	6.42	30	1300	168.3	-	-	-	-	-
2	Rougher	3	9	15	6.50	30	1300	88.8	-	-	-	-	-
3	Rougher	3	9	8.5	10.14	30	1300	81.0	-	-	6.47	12.8	-
4	Rougher	5	25	26.5	1.98	30	1300	-	697.0	-	1.39	105.6	8.82
5	Rougher	5	25	29	1.99	30	1300	-	672.5	-	2.69	127.0	10.64
6	Rougher	5	25	34	2.01	30	1300	-	657.0	-	9.94	37.2	9.67
7	Rougher	4	20	21	1.99	30	1300	-	-	511.2	1.03	24.2	7.04
8	Rougher	4	20	24	2.00	30	1300	-	-	507.2	2.03	-	7.2
9	Rougher	4	20	20	1.99	30	1300	-	-	508.4	3.01	-	9.73
10	Rougher	4	20	24	3.00	30	1300	-	435.4	-	1.74	41.2	1.74
11	Rougher	4	20	21	3.98	30	1300	-	424.4	-	1.70	50.0	0.87
12	Rougher	4	20	23	4.97	30	1300	-	450.4	-	1.80	53.1	0.81
13	Rougher	4	20	24	5.98	30	1300	-	435.6	-	1.74	82.4	0.71
14	Rougher	4	20	22	1.99	30	1300	79.6	-	-	1.59	-	5.01
15	Rougher	4	20	23	3.00	30	1300	80.4	-	-	1.61	-	1.65

Table 4. Flotation parameter and reagent concentration data (cont'd)

Test No.	Flotation	No. of stage	Cond. time min.	Float time min.	pH	Pulp density % S	Impeller speed r.p.m.	Collectors				Na_2SiO_3 kg/t	D200 g/t	M.I.B.C. g/t	H_2SO_4 kg/t
								Mg 98 A3 g/t	Armac T g/t	Armac C g/t	Duo TDO g/t				
16	Rougher	4	20	24.5	4.97	30	1300	-	689.2	-	-	2.76	65.2	-	1.52
	Cleaner	2	6	15	5.02	30	1400	-	-	-	-	-	32.6	-	0.20
17	Rougher	4	20	14	5.00	30	1300	265.6	-	-	-	1.33	-	-	1.08
	Cleaner	2	6	8	5.00	30	1400	-	-	-	-	-	-	-	0.12
18	Rougher	4	20	20	5.00	30	1200	-	595.2	-	-	2.38	70.5	-	1.29
	Cleaner	3	9	16	4.98	30	1400	-	505.9	-	-	-	126.5	-	0.52
20	Rougher	4	20	17	4.99	30	1200	-	-	241.6	-	2.42	-	-	1.67
	Cleaner	3	9	10	4.98	30	1400	-	-	181.3	-	-	-	-	0.29
21	Rougher	2	10	8	3.00	30	1200	-	-	254.4	-	1.02	-	-	1.54
	Cleaner	3	9	12	3.00	30	1400	-	-	152.6	-	-	-	-	0.49
22	Rougher	2	10	11	1.96	30	1200	-	-	285.0	-	1.14	-	41.0	4.99
	Cleaner	3	15	11	2.06	30	1400	-	-	285.0	-	0.85	-	-	8.03
23	Rougher	4	20	24	3.00	30	1300	463.6	-	-	-	1.86	-	16.7	1.07
	Cleaner	3	15	22	3.00	30	1500	695.7	-	-	-	1.39	-	16.7	0.79
24	Rougher	4	20	17	1.97	30	1300	-	149.6	-	-	2.14	-	-	4.85
	Cleaner	3	15	12	2.00	30	1500	-	128.1	-	-	1.60	-	-	8.17
25	Rougher	4	20	16.5	3.00	30	1300	-	168.4	-	-	2.41	-	-	1.33
	Cleaner	3	15	14	3.00	30	1500	-	144.3	-	-	1.80	-	-	5.98
26	Rougher	4	20	17	3.98	30	1300	-	132.4	-	-	1.89	-	-	0.66
	Cleaner	3	15	12	4.00	30	1500	-	113.6	-	-	1.42	-	-	0.38
27	Rougher	4	20	21	1.97	30	1300	-	-	-	465.2	1.86	-	217.6	4.09
28	Rougher	4	20	20	1.99	30	1300	-	-	-	553.2	2.21	-	279.0	4.05
	Cleaner	2	10	12	2.00	30	1500	-	-	-	414.9	1.10	-	99.6	5.68